Shock accelerated vortex ring

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Abstract

The interaction of a shock wave with a spherical density inhomogeneity leads to the development of a vortex ring through the impulsive deposition of baroclinic vorticity. The present fluid dynamics videos display this phenomenon and were experimentally investigated at the Wisconsin Shock Tube Laboratory's (WiSTL) 9.2 m, downward firing shock tube. The tube has a square internal cross-section (0.25 x 0.25 m^2) with multiple fused silica windows for optical access. The spherical soap bubble is generated by means of a pneumatically retracted injector and released into free-fall 200 ms prior to initial shock acceleration. The downward moving, $M = 2.07$ shock wave impulsively accelerates the bubble and reflects off the tube end wall. The reflected shock wave re-accelerates the bubble (reshock), which has now developed into a vortex ring, depositing additional vorticity. In the absence of any flow disturbances, the flow behind the reflected shock wave is stationary. As a result, any observed motion of the vortex ring is due to circulation. The shocked vortex ring is imaged at 12,500 fps with planar Mie scattering.

1 Introduction

Shock-accelerated flows are important to many physical processes encompassing a whole spectrum of length scales. When the large pressure gradients inherent to shock waves encounter density gradients resulting from inhomogeneities within the flow, vorticity is deposited through the baroclinic mechanism ($\nabla\rho \times \nabla p \neq 0$). This vorticity deposition magnifies any perturbations within the density field and leads to the Richtmyer-Meshkov Instability (RMI) [1].

For Shock-Bubble-Interactions (SBI), the density inhomogeneity is created by a spherical soap bubble. Significant work on SBI has been performed by [2, 3]. The present study emphasizes the interaction of a shock wave and a vortex ring generated during the initial shock acceleration of the bubble. Planar Mie scattering was used to image the shocked vortex ring at 12,500 fps. The shock wave reflects off the tube end wall and encounters the vortex ring formed from the first shock acceleration. Because the flow behind the reflected shock wave is relatively stationary, imaging can take place within a single 12×12 cm^2 fused silica window for 3-5 ms. The motion of the vortex ring is a direct result of the circulation deposited upon the first and second shock accelerations.

The videos give an overview of the experimental setup, the facilities at the Wisconsin Shock Tube Laboratory (WiSTL), the method of generating and releasing a soap bubble, and the high speed planar imaging of the shock accelerated bubble and vortex ring. The videos can be found at either of the following links:

- Video 1 (Low Resolution)
- Video 2 (High Resolution).

References

[1] R. D. Richtmyer. Taylor instability in shock acceleration of compressible fluids. *Physica D: Nonlinear Phenomena*, 12:1–3, 1984.

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[3] D. Ranjan, J. Niederhaus, B. Motl, M. Anderson, J. Oakley, and R. Bonazza. Experimental investigation of primary and secondary features in high-mach-number shock-bubble interaction. *Physical Review Letters*, 98, 2007.